Predictability Sieve, Pointer States, and the Classicality of Quantum Trajectories

D. Dalvit, J. Dziarmaga, and W. Zurek

Los Alamos NATIONAL LABORATORY

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- **Pointer states:** **preferred set of states of an open quantum system that are singled out by the persistent monitoring by the environment. They entangle the least with the environment, and are least perturbed by decoherence**

- **They can be found via the predictability sieve criterion, that searches for states that minimize entropy production under unconditional open evolution**

$$\begin{cases} \rho(0) = |\Psi\rangle\langle\Psi| \quad \Longrightarrow \quad \rho = \mathrm{Tr}_{\mathrm{E}}(\rho_{\mathrm{tot}}) \quad \textbf{(uncond. evol.)} \\ \text{Minimize} \quad H_{|\Psi\rangle} = -\mathrm{Tr}(\rho_{|\Psi\rangle} \ln \rho_{|\Psi\rangle}) \end{cases}$$

Eg: For under-damped harmonic oscillator, coherent states $|\Psi\rangle = |\alpha\rangle$

❑ **Conditional evolution:** in reality, we learn about the state of a system by probing its environment.

❑ This leads to an evolution of the system conditioned on the measurement records on the environment ➡ **Quantum Trajectories**

In this work we study various measures of classicality of systems subject to decoherence, undergoing conditional evolution

❑ **Example:** underdamped harmonic oscillator (cavity mode) undergoing continuous quantum measurement (Wiener process)

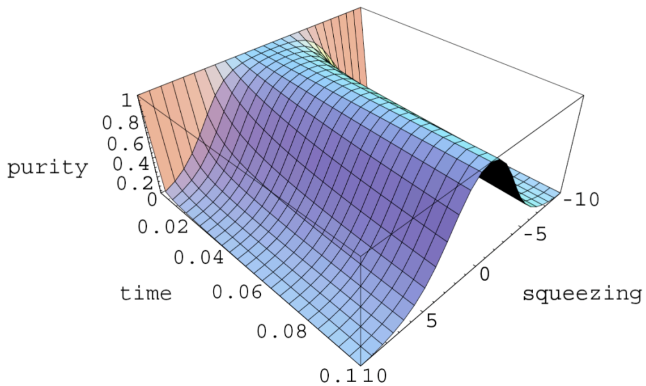
$$d\rho = \underbrace{-i[H_S, \rho]dt + D[a]\rho dt}_{\text{unconditional evolution}} + \underbrace{\sqrt{\eta_x} dW_x \mathcal{H}_\phi[a]\rho \sqrt{\eta_y} dW_y \mathcal{H}_{\phi+\pi/2}[a]\rho}_{\text{conditional evolution}}$$

$$D[a]\rho \equiv a\rho a^\dagger - \frac{1}{2}a^\dagger a\rho - \frac{1}{2}\rho a^\dagger a \qquad \mathcal{H}_\phi[a]\rho = a\rho e^{-i\phi} + \rho a^\dagger e^{i\phi} - \rho\,\mathrm{Tr}(a\rho e^{-i\phi} + \rho a^\dagger e^{i\phi})$$

Gaussian Wigner function: $\mathcal{W}(x,p) = e^{-\alpha(t)[x-x_0(t)]^2 - \beta(t)[p-p_0(t)]^2 + \delta(t)}$

❑ Predictability sieve

selects states that produce least entropy

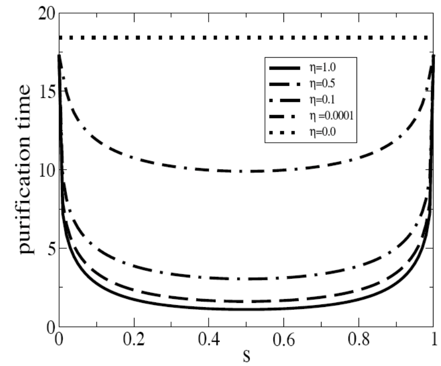


Zero squeezing is optimal

coherent states

❑ Purification time

selects states that are the easiest to find out from the imprint they leave on the environment



$$\eta_x = \eta \sin^2[s\pi/2]$$

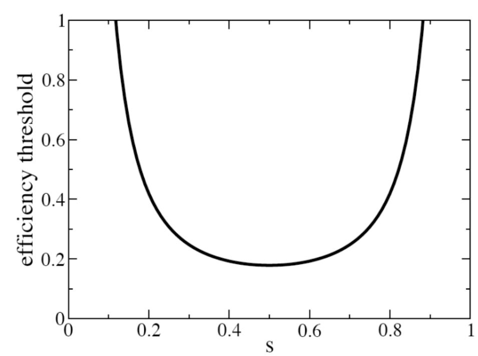
$$\eta_y = \eta \cos^2[s\pi/2]$$

$s = 0.5$ is optimal

coherent states

❑ Efficiency threshold

selects states that can be deduced from measurements on the smallest fraction of the environment



$s = 0.5$ is optimal

coherent states

❑ Purity loss time

selects states for which it takes the longest to lose a set fraction of their initial purity

coherent states

Conclusions:

- ❑ We studied different classicality criteria for open quantum systems undergoing continuous quantum measurement

- ❑ When pointer states (as selected by the predictability sieve unconditional criterion) are well defined, all four conditional criteria agree that indeed pointer states are the most classical states

- ❑ Two examples:
  - underdamped harmonic oscillator ➡ Coherent states are pointers
  - free particle undergoing QBM ➡ Gaussian states are pointers

Reference: PRA **72**, 062101 (2005)